Nocturnal Sleep and Daytime Alertness of Aircrew After Transmeridian Flights

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ABSTRACT

The nocturnal sleep and daytime alertness of aircrew were studied by electroencephalography and the multiple sleep latency test. After a transmeridian flight from London to San Francisco, sleep onset was faster, and although, there was increased wakefulness during the second half of the night, sleep duration and efficiency over the whole night were not changed. The progressive decrease in sleep latencies observed normally in the multiple sleep latency test during the morning continued throughout the day after arrival. Twelve out of thirteen subjects took a nap of around 1h duration in the afternoon preceding the return flight. These naps would have been encouraged by the drowsiness at this time and facilitated by the departure of the aircraft being scheduled during the early evening. An early evening departure had the further advantage that the circadian increase in vigilance expected during the early part of the day would occur during the latter part of the return flight.

INTRODUCTION

Long range transport aircrew operating world-wide routes have to cope with time zone changes and duty periods of varying durations which commence at virtually all times of the day and night. Such a pattern of work leads to irregularity of sleep (9), and the ability of crews to create an acceptable sleep pattern probably depends on the relationship between duty hours and the number of days on route remaining within certain limits (10).

Although, a satisfactory sleep pattern is the crucial factor in determining the acceptability of flight schedules to aircrew, it is the level of alertness during the duty period which is directly relevant to the safety of the operation, and this will also depend on the duration of duty and the circadian rhythm of vigilance (6, 7 & 15). The situation may be complicated further by partial adaptation to a new time zone (16), when the rhythms of the individual are not in synchrony with the environment.

It is in the context of these considerations and in attempting to understand the factors which influence vigilance during duty periods that we have carried out the present study on the nocturnal sleep and daytime alertness of aircrew operating a transmeridian flight between London and San Francisco.

MATERIALS AND METHODS

Subjects. The subjects were 13 healthy males (7 Captains, 2 First Officers, and 4 Flight Engineers) between 31 and 54 (mean 42.1) years old. They weighed between 68 and 91 (mean 81) kg, and their heights were between 173 and 191 (mean 182) cm. They were engaged in active flying duty and were scheduled to make at least one return flight between London and San Francisco during the study. Subjects were recruited from normally scheduled crews, and between one and three members of each crew participated. At the time of the study the United Kingdom was on British Summer Time (BST) and the time zone change with San Francisco (PDT) was 8h. The flight from London to San Francisco departed at 1245h (local time) and was about 10.5h in duration. On arrival at San Francisco (1525h - local time) the subjects were taken to the Stanford Sleep Research Center.

Procedures. Adaptation to a sleep laboratory and the control recordings of sleep and daytime sleep latencies were carried out at the Royal Air Force Institute of Aviation Medicine, Farnborough. During the control period each subject slept in the laboratory overnight and the sleep latency test (3) was carried out at 2h intervals (even GMT hours) during the next day. The individual bedrooms were light-proofed and sound attenuated, and temperature ($20\pm2^{o}C$) and humidity ($55\pm2\%$) were controlled. Each subject was adapted to the laboratory for one night prior to any control or layover (L/O) recordings. Where possible, the control was recorded within the 3 weeks before or after the flight, although with some subjects this period had to be extended to comply with the additional requirement that at least 3 days at home preceded the recording.

During the L/O at Stanford subjects chose their own pattern of rest and activity. In practice, they all adopted a similar strategy and this involved two overnight sleep periods (S1 and S2) and, in all but one case, a short sleep or nap before the return flight at 1745 h (Fig 1). During the L/O all sleeps were recorded and sleep latency tests were carried out every 2h (even GMT hours) when subjects were not sleeping. During the control and L/O periods, alcohol and caffeine intake were restricted. Subjects were allowed 2 measures of alcohol prior to a major sleep period. They were requested to abstain from alcohol and caffeine-containing beverages between sleep latency tests, and meals were avoided during the 30 min preceding each test.

At Farnborough, electroencephalographic (EEG) activity from the C3-A2 (or C4-A1) positions, submental electromyographic (EMG), and bilateral electro-oculographic (EOG) activity were recorded, and EEG activity from the O1-A2 (or O2-A1) positions was also monitored until sleep onset. Recordings were made with silver-silver chloride electrodes filled with electrode jelly applied to the skin with collodion, and resistances of less than 10 Kohms were maintained. During the multiple sleep latency test (MSLT), two channels of EEG activity (C3-A2 or C4-A1, O1-A2 or O2-A1) and bilateral EOG activity were recorded. A Grass 8-10 EEG machine sited in an adjoining room was used, and a paper speed of 10mm/sec was maintained throughout each recording session. The half-amplitiude frequency response was 0.3-35 Hz for the EEG and EOG and 5-70 Hz for the EMG with a selective 50 Hz notch filter in each channel. In addition, respiratory activity was monitored during sleep using nasal thermistors and abdominal strain gauges, and bipolar anterior tibialis EMG was recorded; these data will be presented elsewhere. The sleep records were scored into 30 sec epochs according to conventional criteria (13), and all records from each subject were scored by the same analyst. The latency to the first epoch of stage 1 (drowsy) sleep was

determined for each of the sleep latency tests. Similar techniques were used at Stanford.

Subjective assessments of sleep and well-being were completed before and after each overnight sleep and before each MSLT. Assessments included the Stanford Sleepiness Scale, visual analogue scales related to sleep quality and quantity, alertness and tenseness, and estimations of sleep onset latency and sleep duration.

Statistical Analysis. The sleep variables, together with the subjective assessments of sleep and well-being completed immediately before and after the sleep periods, were analyzed by analysis of variance (ANOVA). Differences between the means for the three overnight sleeps (control, S1 and S2) were compared using the Newman-Keuls shrinking range test (5). Analyses were carried out on both the whole sleep and the first 4h of sleep and on awake activity in the two halves of time in bed. Data from the short sleep period prior to the return flight were included in the analysis of sleep onset latency and of latencies to slow wave and rapid eye movement sleep. The assumptions of ANOVA - homogeneity of variance, normality and additivity - were studied by considering transformations of the raw measures using the maximum likelihood method of Box and Cox (2). The residuals from an ANOVA applied to data using the selected transformation were then examined after the method of Anscombe (1), and, if appropriate, this transformation was applied. However, the means presented in the tables have been calculated from the raw data. Changes in sleep with age were tested by calculating the Kendall rank correlation between age and the sleep variables both from the control alone and from the mean of the three overnight sleeps.

A linear regression model was used to relate the assessments of sleep to the sleep variables. Differences between the slopes and intercepts for individual subjects were tested; and, if possible, a pooled relationship was obtained, and the appropriate correlation coefficients calculated. A similar method was used to relate estimated sleep onset latency and sleep duration to their true values.

Sleep latencies between 1100h and 1900h (local time) on the control day and between 0900h and 1900h during the first day at Stanford were analyzed in separate two-factor ANOVAs where the factors were time-of-day (at five and six levels respectively) and subject. The mean for individual times of day were estimated by the method of Maximum Likelihood to allow for the censoring of data at 20 min. A logarithmic transformation was applied prior to analysis and back-transformed means are presented. Differences between the means were tested using the Newman-Keuls procedure. The sleep latency measured on arrival at Stanford (1900h) was compared with those of the next day and the control day by the Sign test, with the size of the test adjusted to allow for multiple comparisons. A similar procedure was used to compare the sleep latency at 0900h on the control day (when only 4 values under 20 min were recorded) with latencies at later times on the same day.

The subjective assessments obtained immediately before each MSLT were analyzed by a two-factor ANOVA with 13 subjects and 15 times, corresponding to six times on the control day (0900-1900h), one on arrival (1900h), six on the first full day (0900-1900h) and two on the second day (0900 and 1100h). Separate error terms were calculated for within day and between day comparisons by splitting the degrees of freedom for time. Differences between means during the same day were tested by Newman-Keuls, while differences between the value on arrival and those on the next day and the control day were tested according to Dunn (4). Relationships between the assessments and the sleep latencies were

examined by testing the correlation coefficients of the residuals from the respective ANOVAs.

The subjective and objective measures of total sleep time and onset latency were compared by fitting the estimated to the actual values using linear regression. A 95% confidence band for the regression line was obtained by Scheffe's S-method, so that for any objective value x, a 95% confidence interval (y1, y2) for the equivalent subjective measure could be calculated. This provided a test of the hypothesis that the subjective measures were biased, the true values being underestimated when $x>y2$ and overestimated when $x<y1$.

RESULTS

The individual patterns of sleep and MSLT results are displayed in Fig. 2. Following the control sleep period, six sleep latency tests were carried out. During the layover at Stanford all subjects had two overnight sleep periods and, with the exception of one subject, a short sleep before the return flight. Sleep latencies were recorded on arrival at Stanford and between sleep periods.

Changes in sleep with age. The duration of slow wave sleep (stages 3+4) decreased as age increased ($p<0.05$), and this relationship was maintained ($p<0.01$) when the data from the overnight sleeps at Stanford (S1 & S2) were included in the analysis. Total sleep time decreased with increasing age ($p<0.01$), and although it was not possible to show that the amount of awake activity was age-related, there was an indication that the older subjects had more stage 1 (drowsy) sleep, particularly in the early part of the night.

Analysis of sleep. The frequency distribution of total sleep time for the three overnight sleeps (Fig. 3) showed that there were five periods of less than 300 min. Two of these were controls which were curtailed by the subjects for social reasons, and a third was a subject who slept very poorly during the control night. These three subjects were excluded from the analysis of the sleep data, and so results are presented for 10 subjects (Tables I, II, and III). Differences in total sleep time, the sleep efficiency index, or time in bed could not be established, but sleep onset latencies were shorter ($p<0.001$) at Stanford than at Farnborough (Fig. 4). Awake activity and stage 1 sleep in the first 4 h were reduced during S2 compared with control ($p<0.05$), and over the whole night there was a decrease in the duration of stage 1 sleep and there were fewer awakenings ($p<0.05$). However, the duration of awake activity was increased ($p<0.05$) in the second half of time in bed during S1 (60.8 min) and S2 (74.4 min) compared with control (27.5 min).

In general, the analysis of slow wave sleep (SWS) revealed a change in the temporal distribution and an increase in the amount of SWS during the L/O as compared to baseline (Fig. 5). Latencies to SWS (stage 3) were shorter (S1, $p<0.05$; S2, $p<0.01$) at Stanford than at Farnborough (Fig. 4), and the duration of SWS was increased in the first 4h of sleep (S1, $p<0.05$; S2, $p<0.001$) and over the whole night (S1, $p<0.01$; S2, $p<0.001$). During the control night SWS occurred mainly in the early part of sleep, whereas at Stanford there was a greater tendency for it to be distributed throughout the night. During the first 2h of sleep the duration of SWS was increased from 23.0 min in control to 41.1 min in S2 ($p<0.05$) and, excluding the first 2h of sleep, total SWS was greater in S1 (45.2 min, $p<0.01$) and S2 (38.6 min, $p<0.05$) than control (24.9 min). The duration of stage 2 sleep was less in the

TABLE I. CHANGES IN VARIOUS SLEEP MEASURES OVER THE WHOLE NIGHT (n = 10).

Measure	Transformation	Control Sleep	S1	S2
Total sleep time (min)		445.40	455.10	416.50
Sleep efficiency index[+]		0.90	0.86	0.84
Sleep onset latency (min)	$\log_x$	15.00	5.00***	5.00***
Latency (min) to stage 3	$\log_x$	24.20	18.20*	12.90**
Latency (min) to REM sleep	$\log_x$	87.20	73.00	54.60*
REM/NREM ratio		0.26	0.29	0.31
Number of awakenings	$\sqrt{x}$	10.90	9.70 —— * ——	6.00*

*p<0.05; **p<0.01; ***p<0.001.
[+]Sleep Efficiency index = Total sleep time/Time in bed.

TABLE II. CHANGES IN THE DURATION (min) OF SLEEP STAGES OVER THE WHOLE NIGHT (n = 10).

Sleep Stages	Transformation	Control Sleep	S1	S2
Awake	$\sqrt{x}$	21.5	50.5	28.7
1		50.0	40.7	29.7*
Awake + 1	$\sqrt{x}$	71.5	91.2	58.4
2		255.8	234.0	210.1*
3		39.8	51.3	54.3
3+4	$\sqrt{x}$	47.9	74.6**	79.7***
REM		91.8	105.0	96.5

*p<0.05; ***p<0.001.

TABLE III. CHANGES IN THE DURATION (min) OF SLEEP STAGES IN THE FIRST 4H (n = 10).

Sleep Stage	Transformation	Control Sleep	S1	S2
Awake	$\log_x$	8.9	7.4 ——— * ———	5.1
1	$\log_x$	20.4	12.6	9.9*
Awake + 1	$\log_x$	29.3	20.0	15.0*
2		139.6	117.1**	105.3***
3		28.6	36.6	41.7
3+4	$\sqrt{x}$	36.3	52.7*	63.3***
REM		33.0	47.8*	53.9**

*p<0.05; **p<0.01; ***p<0.001.

first 4h of sleep in S1 (p<0.01) and S2 (p<0.001) than in the corresponding period of the control night, but over the whole night this reduction was seen only in S2 (p<0.05).

As shown in Fig. 4, the latency to rapid eye movement (REM) sleep was shorter during S2 than control (p<0.05). Although REM sleep duration was increased during the first 4h of sleep at Stanford (S1, p<0.05; S2, p<0.01), there was no change over the whole night.

There were only minor differences between the overnight sleeps at Stanford. There was less awake activity in the first 4h of sleep (p<0.05) and fewer awakenings (p<0.05) during S2 compared with S1. The hypnograms (Fig. 6) show the three sleep patterns (control, S1 and S2) from a single subject, and illustrate the changes in sleep that were observed at Stanford.

The mean total sleep time of the short sleep taken before the return flight by 12 of the 13 subjects was 69.2 min. Latencies to sleep onset (15.0 min), stage 3 sleep (25.7 min) and REM sleep (74.9 min) were not different from those of the control sleep.

Multiple sleep latency test. During the control day (0900-1900h) at Farnborough, sleep latencies exhibited the usual pattern (Fig. 7) with an increase in the tendency to sleep from 0900-1300h (p<0.05) and a decrease from 1500-1900h (p<0.05). However, after the first overnight sleep at Stanford the sleep latencies (0900-1900h) showed increasing drowsiness over the day (Fig. 8). The sleep latency at 1900h was shorter than at 1700h (p<0.05), 1100-1500h (p<0.01) and 0900h (p<0.001). After the second overnight sleep there were fewer latency tests but, including the latency to stage 1 sleep of the nap as an additional value, there was a similar increase in sleep tendency from 0900-1300h, though it was not possible to establish a significant effect.

Subjective assessments. The assessments obtained before and after the three

overnight sleep periods (control, S1, and S2) are given in Table IV. Subjects reported on the Stanford Sleepiness Scale (SSS) that they felt more sleepy before S1 and S2 ($p<0.001$) than before the control sleep. After S1 and S2, their sleepiness rating decreased ($p<0.01$) to a level consistent with that after the control night. As shown in Fig. 9, quality of sleep was assessed as better at Stanford than at Farnborough (S1, $p<0.05$; S2 $p<0.01$), and this correlated with shorter latencies to stage 3 and REM sleep ($p<0.05$). Subjects also felt that they had obtained a satisfactory amount of sleep on S1 and S2, and this correlated with the increase in the duration of stage 3 sleep ($p<0.01$) and the reduction in the number of awakenings ($p<0.05$).

There was a positive correlation between estimated and actual sleep onset latencies ($p<0.01$) with a fitted relationship $\log y = 1.8 + 0.46 \log x$ where y (min) is the estimated and x (min) is the actual value. The corresponding relationship for total sleep time ($p<0.001$) was $y = 102.7 + 0.691\ x$. Subjects overestimated their short (<12 min) sleep onset latencies ($p<0.05$), and underestimated their long (>410 min) sleep periods ($p<0.05$).

During the control day at Farnborough there were no differences in assessments of tenseness, alertness or sleepiness completed before sleep latency tests, but on arrival at Stanford subjects reported increased sleepiness before the 1900 h test: SSS scores were higher and alertness ratings were lower than those observed on the control day and from 0900-1500h on the first day at Stanford. After S1 subjects felt more sleepy and less alert at 1500h and at all later times than at 1100h ($p<0.05$). There was a residual negative correlation between the SSS score and sleep latency ($r = -0.16$, $n=168$, $p<0.05$), shorter sleep latencies tending to be associated with increased subjective sleepiness. The large residual correlation ($r = -0.68$, $n=168$, $p<0.001$) between the SSS score and assessment of alertness indicated the close agreement between these two similar subjective measures.

DISCUSSION

The age-related differences in total sleep time and SWS observed in this study were consistent with the age range of the subjects, and were present in the control observations at

TABLE IV. CHANGES IN SUBJECTIVE ASSESSMENTS OF SLEEP AND WELL-BEING BEFORE AND AFTER MAJOR SLEEP PERIODS (n = 13).

Assessment	Control Sleep	S1		S2	
SSS before sleep	3.54	5.00***	**	4.85***	**
SSS after sleep	3.08	2.85		2.77	
Sleep quality	43.0	59.2*		64.9**	
Sleep quantity	61.8	58.5		56.2	

*p<0.05; **p<0.01; ***p<0.001.

Farnborough and in the sleeps at Stanford. There was no evidence that the older subjects had more difficulty sleeping in the new time zone, and alterations in sleep after the outward flight were similar in all age groups. These changes may be attributed to various factors such as the previous pattern of sleep and wakefulness, the length of prior wakefulness, and the time of day at which sleep occurred.

Although sleep during the nights before the outward flight was not recorded, subjects reported durations of 7h or less on some occasions in the preceding 3 or 4 nights, and, of course, subjects were awake for more than 20h before the first sleep in the new time zone. The increased duration of SWS observed in the two overnight sleeps at Stanford (S1 and S2) is likely to be due to this extended period of wakefulness (14) and, possibly, to some sleep loss during the days before the flight. Sleep onset was faster and this change was also probably related to the preceding sleep deprivation. During the first 4 h of the night, which would coincide with part of the sleep period at home, sleep continuity was similar during S1 and control, and there was evidence of improved sleep during S2. However, the less restful sleep during the second half of each night was likely to be due to difficulty in sleeping at a time of day when the individuals would normally be awake.

The appearance and distribution of REM sleep during L/O were primarily influenced by the time at which the sleep occurred. The shorter latencies to REM sleep were consistent with subjects retiring in the 'early morning' of their circadian rhythm at home. It is likely that by the second night subjects may have adapted by about 2h, and so their circadian rhythm would have been displaced by about 6h from the new time zone. Bedtime in the new time zone around 2200h would correspond to 0300-0400h of their circadian rhythm, and previous studies have indicated that this bedtime is associated with a short latency to REM sleep and the highest propensity for REM activity (11, 14).

The latencies to sleep data recorded during MSLT's on the control day showed the characteristic pattern. Sleep tendency increased over the first few hours after wakening, but reversed later in the day. However, after both the first and second nights in the new time zone, sleep latencies decreased with time awake, and the subjects reported that they felt more sleepy. This pattern of sleep tendency revealed by the multiple sleep latency test arises from the changed relationship between the circadian rhythm of alertness and the new environment. The increase in drowsiness with time awake would normally be reversed by the rising phase of the circadian rhythm during the latter half of the day, but the rising phase would have occurred much earlier in the day in California, and so drowsiness would persist during the afternoon.

Concerning the operational significance of these findings, the studies suggest that overall sleep was not unduly altered in the new time zone, although the second halves of the night were more interrupted by wakefulness. Further, sleep latencies during the day suggest that drowsiness would have persisted up to the time of the return flight even with the progressive adaptation of the circadian rhythm of alertness. However, on the day of the return flight all but one of the 13 subjects took a short sleep of around 1h duration during the afternoon, and such sleeps improve alertness in sleep deprived subjects over the next 8h (8.12). In addition, although the increase in alertness related to the circadian rhythm of the individual was displaced, it would still have influenced vigilance during the latter part of the flight which terminated about midday local time.

The most advantageous time for the return flight from San Francisco would therefore appear to be in the early evening. However, the tendency to sleep in the afternoon would become less insistent with successive days in the new time zone as the rhythm of alertness adapts to local time, and so a L/O of limited duration may be appropriate. Whereas, a departure during the early afternoon may not allow a nap beforehand, and the flight may terminate without the benefit of the rising phase of the circadian rhythm of vigilance.

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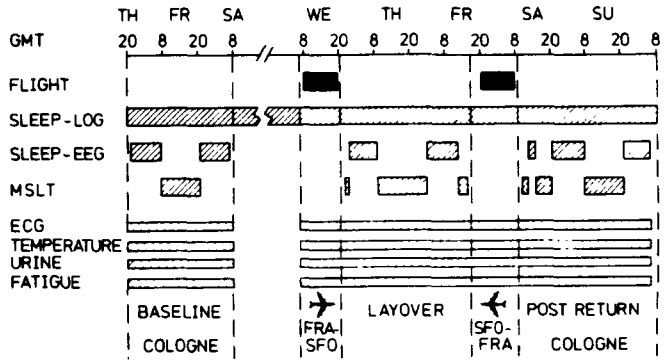

Figure 1.- Overview of time lines for the data collection of the flight schedule Frankfurt-San Francisco.

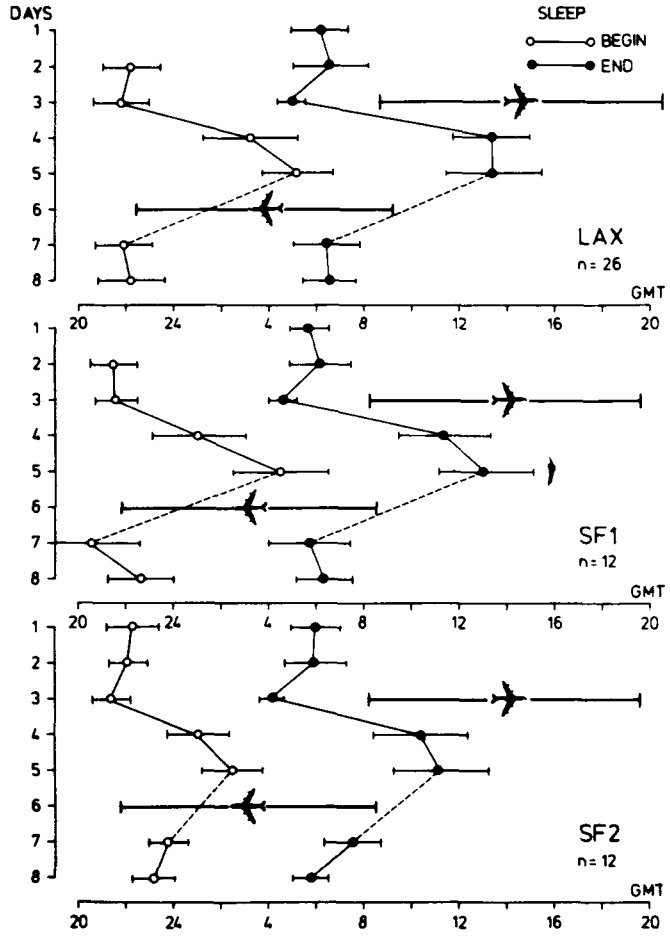

Figure 2. Subjective ratings of beginning and end of sleep during control, layover and post-return nights. Presented are means (±S.D.) of the three different groups. (Numbers of days at the vertical axis refer to days beginning at 2400 GMT.)

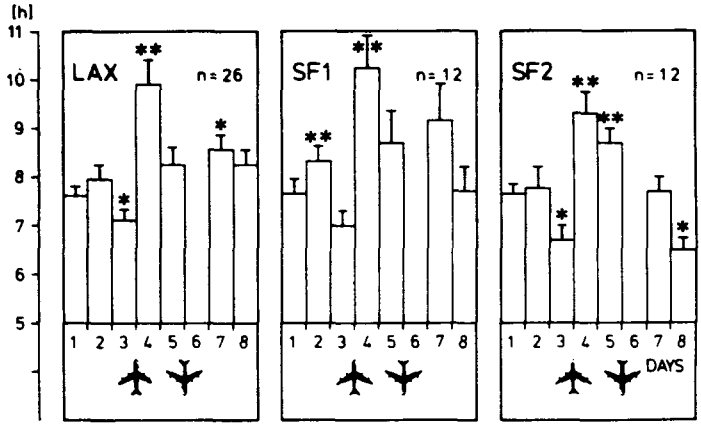

Figure 3. Subjective ratings of sleep duration during control, layover, and post-return nights (means +/- S.E.). * p<=0.05; ** p<=0.01 for differences from sleep period of day 1.

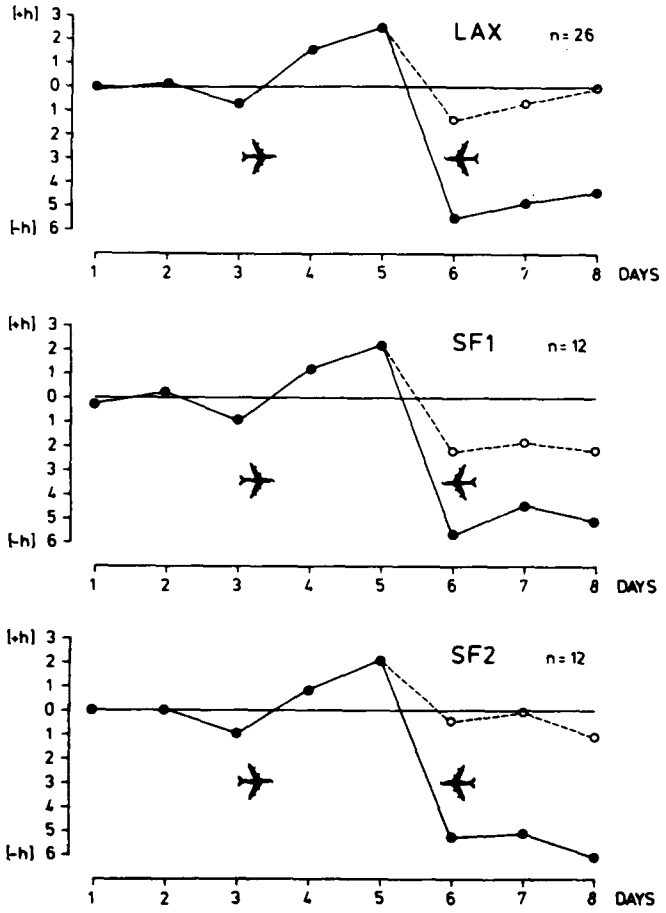

Figure 4. Sleep balance: accumulated deviations of subjectively rated sleep duration from control nights (day 1 and day 2). Values do not include short extra sleep periods (naps). Open circles and dashed lines represent sleep balance including sleep in the afternoon following return flight.

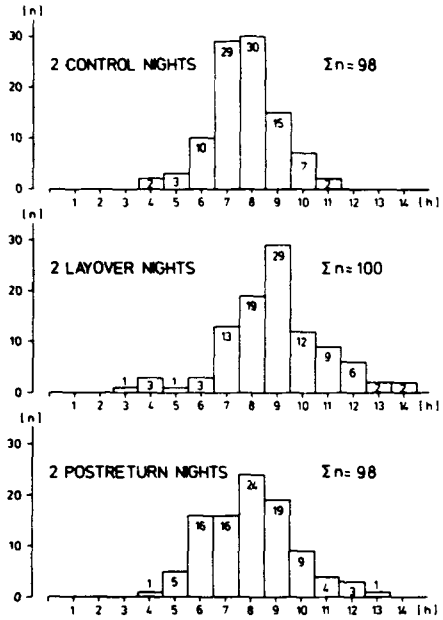

Figure 5. Histogram of subjectively rated sleep duration of all three groups together. Combined are two nights each from the control, layover and post-return period. (Note: sleep period immediately preceding flight schedule not included).

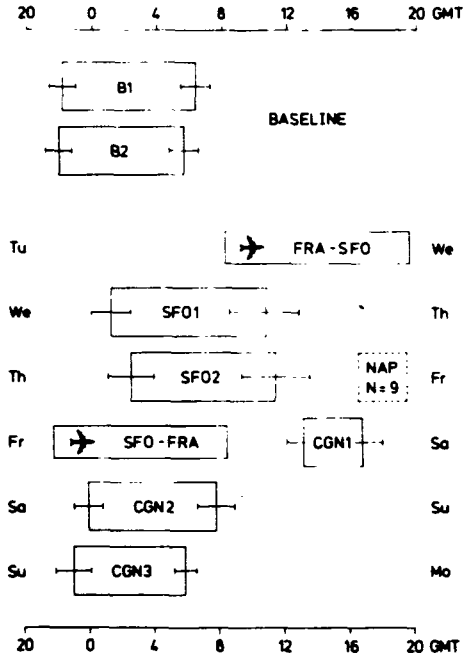

Figure 6. Time schedule of sleep periods and flights. Time axis is chosen from 2000 to 2000 GMT. Bars for sleep periods show standard deviation for light off and on. Baseline recordings were taken several days before flight to SFO.

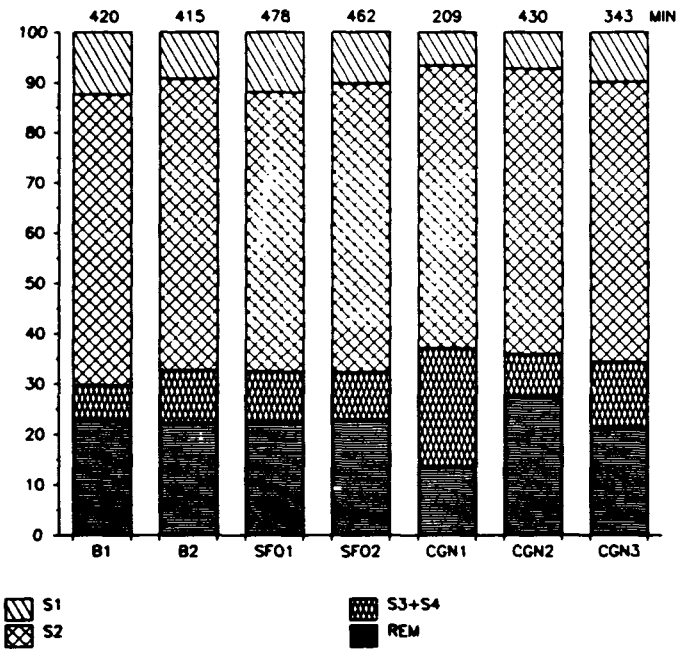

Figure 7. Mean percentage of total sleep time (TST) for sleep stages. Means (N = 12) are shown for seven sleep periods. Absolute TST values (min) are given on top of the bars.

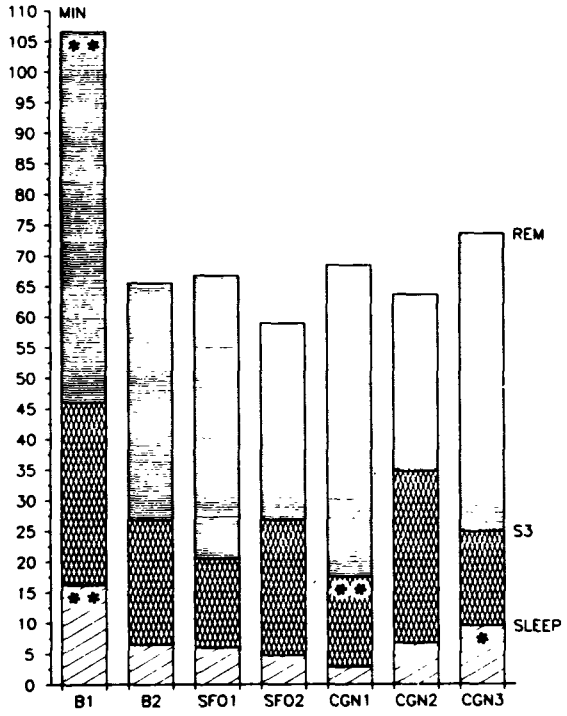

Figure 8. Median (N=12) latencies to the first ten minutes of persistent sleep, to slow-wave sleep (S3), and to REM sleep. Significant differences from baseline values (B2) are indicated (*p<0.05, **p<=0.01, Wilcoxon-matched-pairs-signed-rank test).

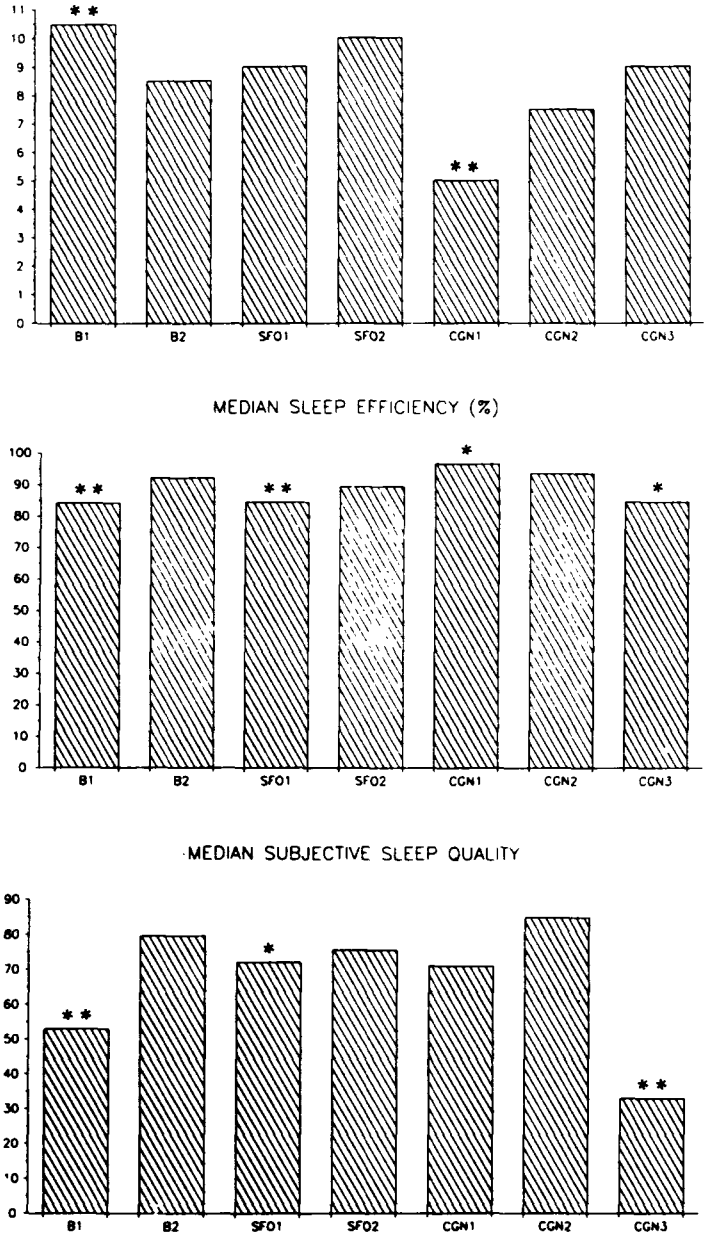

Figure 9. Sleep efficiency, number of awakenings, and subjective ratings of sleep quality for seven sleep periods. Significant differences from baseline (B2) are indicated (* p < = 0.05. ** p < = 0.01).

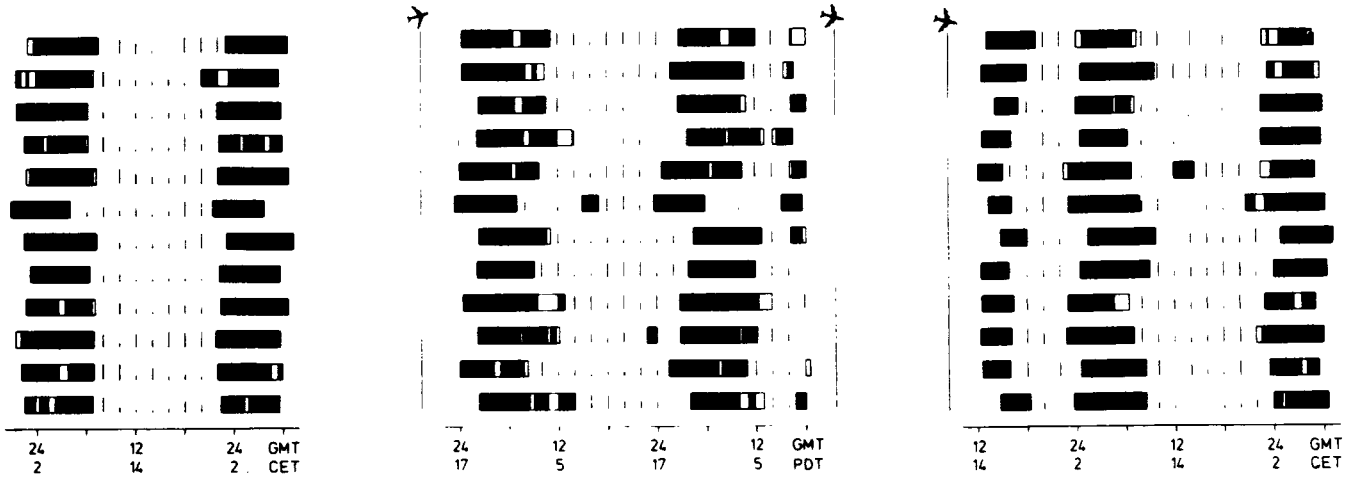

Figure 10. Sleep pattern and multiple sleep latency test (MSLT). Sleep periods in black, wake times in white. Vertical lines between sleep periods represent MSLT; their height is sleep latency in minutes.

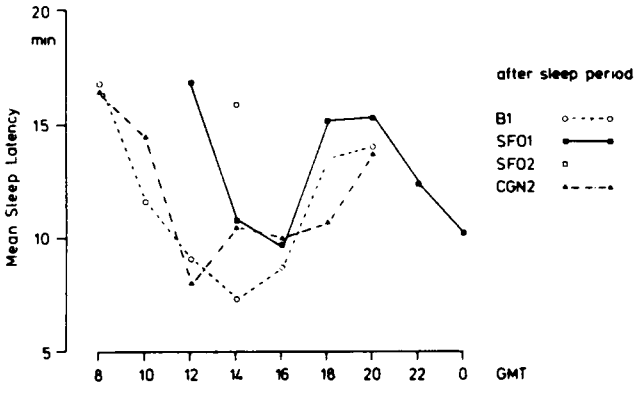

Figure 11. Mean MSLT after sleep periods B1, SFO1, SFO2, CGN2.

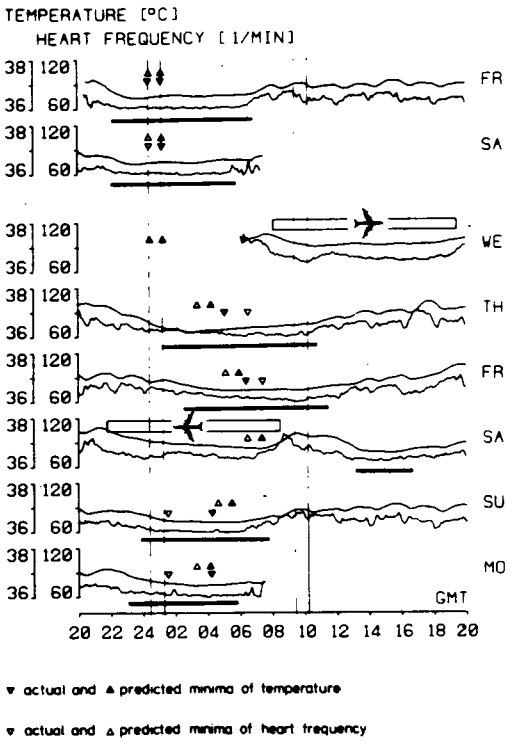

Figure 12. Means for temperature (upper curves) and heart rate (lower curves) before, during and after flights. Vertical lines indicate position of minima during baseline and after complete shift by 9h (solid lines: temperture; dashed lines: heart rate).

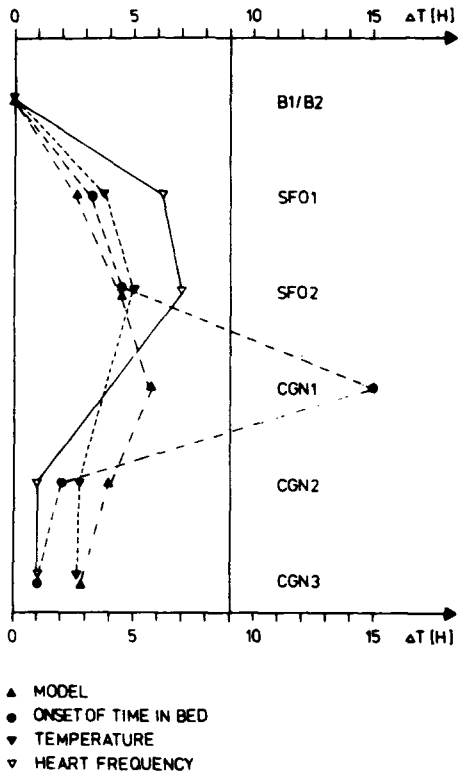

Figure 13. Shifts in acrophases relative to baseline position.